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Rubidium-Strontium and Samarium-Neodymium Chronology of Meteorites

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Rubidium-Strontium and Samarium-Neodymium Chronology of Meteorites

Definition

This is a review of Rb-Sr and Sm-Nd chronology of meteorites. The theory and application of Rb-Sr and Sm-Nd isotopic systems to meteorite samples is discussed. This is followed by a brief synopsis of the key developments that led to the widespread use of the chronometric systems today. Finally, some of the key age results derived from these systems are presented.

Introduction

The Rb-Sr and Sm-Nd isotopic systems have been used to date meteorite samples providing a temporal framework for events that occurred throughout the history of the Solar System. These isotopic systems are complementary to one another, as well as to other chronometers such as Al-Mg, Mn-Cr, U-Pb and Lu-Hf, but have particular characteristics that make them particularly well suited to age date differentiated meteorites. Below the historical development and application of the Rb-Sr and Sm-Nd systems to the chronology of meteorites is discussed.

Rb-Sr Chronology of Meteorites

Rb-Sr isotopic systematics

The Rb-Sr isotopic system has been used to constrain the evolution of Solar System since it was first applied to basaltic achondrite meteorites by Papanastassiou and Wasserburg (1969). Although this method was first used to obtain an age by Hahn et al. (1943), it was not until Nier-type mass spectrometers (Mass Spectrometers, Springer Reference) were readily available that it came into widespread use. The principles of the Rb-Sr system and its' application to geologic materials are discussed by several authors (e.g., Dicken, 2002; Faure, 1998; Rb-Sr dating, Springer Reference) and are not reiterated here. However, it is important to understand that Rb-Sr ages are based on the isochron method in which several aliquots, usually separated mineral fractions, of a sample are analyzed for $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios and then plotted on an isochron diagram. The slope regressed through the data defines the age of the sample and the y-intercept defines the initial Sr isotopic composition of the fractions at the time they formed from a common source. Uncertainty in the ages is based primarily on the scatter of the data points on the isochron diagram. Ages determined from this method are only valid if the aliquots that define the isochron regression were in isotopic equilibrium when they formed. Thus, the age records the time elapsed since the aliquots shared a common Sr isotopic composition. This is usually considered to be when the minerals crystallized from a magma.

In order to obtain an age from the slope of the isochron, the ^{87}Rb decay constant must be known. Unfortunately, the decay of ^{87}Rb to ^{87}Sr is a low energy transformation of only 275 keV, involving the emission of a beta particle and an antineutrino ($^{87}_{37}Rb \rightarrow\ ^{87}_{38}Rb + \beta + \bar{\nu} + Q$), and is therefore difficult to measure accurately. As a result, meteorite Rb-Sr ages have been calculated using several decay constants ranging from 1.39 x 10^{-11} yr^{-1} to 1.42 x 10^{-11} yr^{-1} (Aldrich et al., 1956; Steiger and Jäger, 1977). Ages reported in the literature must therefore be adjusted to a common decay constant for inner comparison. After a detailed analysis of published ^{87}Rb decay constants, Begemann et al. (2001) suggested using the value of 1.402 x 10^{-11} yr^{-1} determined by Minster et al. (1982) and Shih et al. (1985). This is the value most commonly used for meteorite and lunar chronology studies today. Another factor that must be considered when examining Rb-Sr data in the literature is the range of ^{87}Sr/^{86}Sr values obtained on standards. This is complicated by the fact that early investigations used different isotopic standards, such as Seawater or plagioclase separated from meteorites. In the mid 1970's the NBS-987 standard became widely used, and individual laboratories often normalized their data to the certified ^{87}Sr/^{86}Sr ratio of 0.71014. More recently, the consensus of the Rb-Sr isotope community is that ^{87}Sr/^{86}Sr value of this standard is 0.71025. In this discussion all ^{87}Sr/^{86}Sr data are re-normalized to this ^{87}Sr/^{86}Sr value and Rb-Sr ages are recalculated using an ^{87}Rb decay constant of 1.402 x 10^{11} yr^{-1}.

Chondrites, angrites, and eucrites

Ideally the slope of the Rb-Sr isochron diagram is used to constrain the age of a sample. In some cases ancient Rb-Sr ages have been obtained for individual basaltic achondrites, such as Ibitira and Juvinas (Allègre et al., 1975; Birck and Allègre, 1978), that record the crystallization age of the sample. However, many meteorite samples either have limited internal variation in ^{87}Rb/^{86}Sr or demonstrate evidence for significant disturbance of the Rb-Sr system by secondary processes occurring on their parent bodies or on Earth. To address these problems, ages of individual samples have been calculated from an assumed initial ^{87}Sr/^{86}Sr ratio. In one of the first investigations of meteorite samples Papanastassiou and Wasserburg (1969) measured Rb-Sr in a group of basaltic achondrites obtaining an age of 4.35 ± 0.24 billion years (Ga) and an initial ^{87}Sr/^{86}Sr of 0.699099 ± 0.000044 (Figure 1). This is a whole rock isochron and is based on the premise that all the analyzed meteorites are derived from a common source region at the same time. As such, the initial Sr isotopic composition determined from the isochron records the value of the source region. This initial value is known as BABI (Basaltic Achondrite Best Initial) and is used as a reference point for model ages calculated from the Rb-Sr isotopic compositions of other meteoritic samples. BABI model ages have proven invaluable in constraining the relative age of the earliest meteorite samples (e.g., Papanastassiou, 1970) due to the disturbed nature of their Rb-Sr isotopic systematics.

A summary of initial ^{87}Sr/^{86}Sr values from the most ancient meteorite samples is presented in Table 1. From this Table it is apparent that BABI is not the least radiogenic Sr isotopic composition measured in the Solar System. This reflects the fact that other meteorites samples, such as Calcium-Aluminum-rich Inclusions (CAIs) from carbonaceous chondritic meteorites and angrite meteorites, are older than the basaltic achondrites. The initial Sr isotopic compositions measured by Gray et al. (1973) of these samples were given acronyms as follows:

Allende (ALL) and Angra dos Reis (ADOR). Subsequent measurements on the same samples types are often slightly different than the original values and are listed separately in Table 1.

Table 1. Initial Sr Isotopic Compositions of Ancient Samples

Sample	Measured Initial $^{87}Sr/^{86}Sr$	Normalized Initial $^{87}Sr/^{86}Sr$ [a]	Reference
Allende CAI D7 (≡ALL)	0.69876 ± 0.00004	0.69887 ± 0.00004	Gray et al. (1973)
Allende CAI N17	0.69861 ± 0.00004	0.69872 ± 0.00004	Tatsumoto et al. (1976)
Allende CAI 3529-30	0.69885 ± 0.00002	0.69891 ± 0.00002	Podosek et al. (1991)
Allende CAI Al3S4	0.69894 ± 0.00001	0.69894 ± 0.00001	Marks et al. (2013)
Chondritic meteorites	0.69885 ± 0.00001	0.69895 ± 0.00001	Minster et al. (1982)
Angra dos Reis (≡ADOR)	0.69884 ± 0.00004	0.69895 ± 0.00004	Papanastassiou (1970)
Angra dos Reis	0.69897 ± 0.00002	0.69897 ± 0.00002	Nyquist et al. (1994)
LEW 86010	0.69897 ± 0.00001	0.69897 ± 0.00001	Nyquist et al. (1994)
Basaltic Achondrites (≡BABI)	0.69899 ± 0.00004	0.69910 ± 0.00004	Papanastassiou & Wasserburg (1969)
Basaltic Achondrites	0.69899 ± 0.00004	0.69909 ± 0.00004	Birck & Allègre (1978)

a. Data normalized to NBS-987 = 0.71025. Initial isotopic compositions calculated from isochron or least radiogenic sample using of $\lambda^{87}Rb = 1.402 \times 10^{11}$ yr^{-1}. More significant figures are often available from original references.

Martian meteorites

Whereas obtaining internal Rb-Sr isochron ages for the most ancient meteorites has often proven to be a difficult task, defining Rb-Sr ages for young meteorites from differentiated bodies, such as Mars and the Moon, has been less difficult. The first unequivocal young Rb-Sr was determined for the meteorite Nakhla which belongs to the SNC (shergottite-nakhlite-chassigny) group of meteorites. Ages of 1.30 ± 0.02 Ga and 1.23 ± 0.01 Ga were determined by Papanastassiou and Wasserburg (1974) and Gale et al. (1975). Young ages of 163 to 178 million years (Ma) were later obtained on the related Shergotty and Zagami meteorites by Nyquist et al. (1979a) and Shih et al. (1982). Initially the young ages obtained on the SNC meteorites were interpreted to reflect isotopic re-equilibrium associated with extensive metamorphism of their parent body. The extent of metamorphism required to reset the Rb-Sr system led Nyquist et al. (1979b) to conclude that the parent body was very large, and likely to be the planet Mars. Later petrologic work (Jones. 1986) and isotopic analysis involving the Sm-Nd chronometer (Borg et al. 1997) demonstrated that the ages most likely recorded a crystallization event rather than a metamorphic event. Numerous Rb-Sr (and Sm-Nd) ages have now been obtained of the SNC suite of Martian meteorites. The shergottites define 4 general age groups of ~170 Ma, ~330 Ma, ~475 Ma, and ~575 Ma (see summaries by Nyquist et al., 2001; Borg and Drake, 2005). Several additional nakhlites have also been dated at 1.3 Ga (e.g., Shih et al., 1999). An age of 2089 ± 81 Ma has been reported for NWA7034 meteorite (Agee et al., 2013). This meteorite is a breccia, and mineral fractions were derived from the bulk sample. Implicit in this age determination is the assumption that all of the breccia fragments and matrix minerals crystallized from the same magma at the same time. Finally an Rb-Sr age of 3.90 ± 0.04 Ga was determined on secondary carbonates hand-picked from the orthopyroxenite ALH84001 (Borg et al., 1999).

Initial $^{87}Sr/^{86}Sr$ values have been determined from the Rb-Sr isochrons and demonstrate a huge range from ~0.701 (e.g., Borg et al., 1997) to 0.723 (e.g., Nyquist et al. 1979a). The initial $^{87}Sr/^{86}Sr$ ratios, along with initial $^{143}Nd/^{144}Nd$ ratios, indicate that the shergottites are derived from source regions that have elemental abundances that range from incompatible-element depleted to incompatible-element enriched. The shergotites have consequently been sub-divided on this basis (Symes et al., 2008). A sampling of Rb-Sr ages determined for the various types of Martian meteorites is presented in Table 2, with an emphasis on the first age determinations for each meteorite.

Table 2. Representative Ages and Initial Sr Isotopic Compositions of Martian Meteorites

Sample	Rb-Sr age	Initial $^{87}Sr/^{86}Sr$	Reference
Zagami (E)	171 ± 8 Ma	0.721566 ± 0.000082	Shih et al. (1982)
EET79001B (I)	172 ± 18 Ma	0.71217 ± 0.00003	Nyquist et al. (1986)
ALH77005 (I)	187 ± 12 Ma	0.71037 ± 0.00005	Shih et al. (1982)
QUE94201 (D)	327 ± 12 Ma	0.701298 ± 0.000014	Borg et al. (1997)
Nakhla	1.30 ± 0.02 Ga	0.70232 ± 0.00006	Papanastassiou and Wasserburg (1974)
Chassigny	1.22 ± 0.01 Ga	0.70253 ± 0.00004	Nakamura et al. (1982)

Letters after shergottite names refer to incompatible-element characteristics of their source regions (E) = enriched, (D) = depleted, and (I) = intermediate.

Lunar meteorites

Several relatively young ages have also been determined for lunar meteorites. For the most part, however, Rb-Sr ages have been confined to basaltic samples. Like highland rocks returned by the Apollo missions, the Rb-Sr isotopic systematics of highlands clasts present in brecciated meteorites appear to be disturbed by metamorphic processes associated with impact. A good example of such disturbance is in anorthositic meteorite Y86032 that yields a Rb-Sr age of 4.62 ± 0.89 Ga (Nyquist et al., 2006). Metamorphism appears to result in the mobilization, and loss, of Rb from the mafic mineral fractions. Thus, Rb-Sr isochrons are generally disturbed to the older side of the age spectrum.

A few basaltic lunar meteorites have been dated using the Rb-Sr chronometer. An age of 2990 ± 18 Ma was reported for the incompatible-element enriched LaPaz 02205 meteorite (Rankenburg et al. 2007), whereas low Ti-basaltic meteorites NWA 032 and NWA 4734 yielded ages of 2947 ± 16 Ma (Borg et al., 2009) and 3083 ± 42 Ma (Elardo et al., 2014), respectively. Many of the lunar meteorites were found in desert environments and consequently have Rb-Sr systematics that have been disturbed by terrestrial weathering. The Rb-Sr systematics of NWA4734, for example, is based on a two point tie-line. Luckily this age was confirmed by a more robust Sm-Nd isochron that was derived from additional mineral fractions. Ages determined on lunar basaltic meteorites demonstrate that these samples have crystallization ages that are younger than any samples returned by the Apollo and Luna missions. In fact, the meteorites are the youngest lunar samples known (Borg et al., 2004). This is consistent with the hypothesis that they are derived from different localities on the Moon.

Sm-Nd Chronology of Meteorites

Introduction

Samarium-neodymium ages of meteorites are derived from two independent parent-daughter isotope pairs. The first decay reaction is ${}^{147}_{62}Sm \rightarrow {}^{143}_{60}Nd + \alpha + Q$. The parent isotope ^{147}Sm has a well defined half-life of 106 billion years corresponding to a ^{147}Sm decay constant of 6.54 x 10^{-12} yr^{-1}. Like the ^{87}Rb-^{87}Sr decay system (Rb-Sr dating, Springer Reference), this system is based on the isochron method in which separated mineral fractions of an individual samples are analyzed for ^{147}Sm/^{144}Nd and ^{143}Nd/^{144}Nd and plotted on an isochron diagram (Dicken, 2002; Faure, 1998; Sm-Nd dating, Springer Reference). Ages determined from this method are only valid if the aliquots that define the isochron regression were in isotopic equilibrium. It should be noted that different laboratories have used different Nd isotopic ratios, including ^{142}Nd/^{144}Nd, ^{146}Nd/^{144}Nd, and ^{148}Nd/^{144}Nd, as well as different isotopic compositions, to correct for instrument mass fractionation. Caution must therefore be taken when comparing the initial ^{143}Nd/^{144}Nd values reported from different laboratories.

The second decay reaction is ${}^{146}_{62}Sm \rightarrow {}^{142}_{60}Nd + \alpha + Q$. The parent isotope, ^{146}Sm, is extinct so this system can only be used to date samples older than ~4.3 Ga. As a consequence this system is used almost exclusively to date meteorite samples. Model ages are obtained by determining the initial ^{146}Sm/^{144}Sm ratio of the sample at the time it formed from the slope of a ^{144}Sm/^{144}Nd-^{142}Nd/^{144}Nd isochron plot. A model age is defined by the time required to produce the initial ^{146}Sm/^{144}Sm ratio of the sample starting from the initial ^{146}Sm/^{144}Sm ratio Solar System at 4567 Ma. In turn, the initial ^{146}Sm/^{144}Sm ratio of the Solar System is calculated from the initial ^{146}Sm/^{144}Sm ratio measured on a reference sample of known age. The reference samples used to determine ^{146}Sm-^{142}Nd ages have traditionally been angrite meteorites (e.g., Nyquist et al., 1994), although eucrites (Boyet and Carlson, 2010) and CAIs (Marks et al., in review) have been proposed more recently. One obstacle to the application of the short-lived Sm-Nd system to date meteorite samples has been defining the appropriate half-life for ^{146}Sm. Values of 68 Ma (Kinoshita et al., 2012) and 103 Ma (Friedman et al., 1966; Meissner et al., 1987) have both been used to calculate ^{146}Sm-^{142}Nd ages. Either half-life appears to reproduce Pb-Pb ages on the oldest samples, because the uncertainties on the ^{146}Sm-^{142}Nd ages are often larger than the difference in ages calculated using the 68 Ma and 103 Ma half-lives. The 103 Ma half-life appears to better reproduce the Pb-Pb and ^{147}Sm-^{143}Nd ages of young lunar samples, however (Marks et al., in review).

The chemical purification procedures developed to separate Sm and Nd from matrix start with the purification of Rb-Sr. As a consequence, most Sm-Nd isochrons obtained today on meteorite samples are accompanied by Rb-Sr data from the same fractions. The simultaneous analysis of Sm-Nd and Rb-Sr has made the interpretation of some ages significantly easier, because concordant Sm-Nd and Rb-Sr ages typically indicate that these chronometers record igneous crystallization. Co-analysis of Sm-Nd and Rb-Sr has demonstrated that the Sm-Nd system is less easy to disturb by post crystallization metamorphism and secondary alteration than the Rb-Sr system. Thus, many of the most reliable ages obtained on meteorites are currently derived from the Sm-Nd system.

Primitive achondrites

Lugmair (1974) first proposed using the ^{147}Sm-^{143}Nd system as a dating method and demonstrated its feasibility by obtaining an age of 4.56 ± 0.08 Ga on the eucrite Juvinas. This was followed by application of the Sm-Nd system to the angrite Angra dos Reis, yielding an age of 4.55 ± 0.04 Ga (Lugmair and Marti, 1977), as well as to lunar samples (e.g., Lugmair et al., 1976). Early in the development of the Sm-Nd chronometer, evidence for live ^{146}Sm was sought, but the results were equivocal (Notsu and Mabuchi, 1973; Lugmair et al., 1975). The first clear evidence for live ^{146}Sm came from analysis of Angra dos Reis by Lugmair and Marti (1977). They reported a 60 ppm difference between phosphate and pyroxene mineral fractions and attributed the difference to radiogenic decay of ^{146}Sm. The ^{146}Sm-^{142}Nd and ^{147}Sm-^{143}Nd isotopic systems have been used to date many differentiated achondrite meteorites including angrites, eucrites, mesosiderites, a brachinite, and an alcapulcoite. A forthcoming manuscript by Marks et. al (in review) provides a summary of some of these results.

Martian and lunar meteorites

The Sm-Nd system has also been applied to the Martian suite of meteorites that includes shergottites (basalts), nakhlites (clinopyroxenites), chassignites (dunites), as well as an orthopyroxenite (ALH84001). Application of the Sm-Nd chronometer to these samples is very difficult because they have very low abundances of Sm and Nd, contain phosphate minerals that host the vast majority of the Sm and Nd in the rock, and often contain copious amounts of impact melt. As a consequence, mineral fractions derived from Martian meteorites have some of the lowest abundances of Nd of any planetary sample. Not surprisingly, initial attempts to date Martian meteorites yielded highly disturbed Sm-Nd isochrons (e.g., Shih et al., 1982) that seemed to confirm the original hypothesis that these meteorites underwent extensive metamorphism. Thus, young Rb-Sr and U-Th-Pb ages determined from these meteorites were interpreted to record the timing this event (Papanastassiou and Wasserburg, 1974; Nyquist et al. 1979a, 1979b; Chen and Wasserburg, 1986). However, Borg et al. (1997) obtained high purity mineral fractions from QUE94201 that were devoid of impact melt glass that yielded young concordant Rb-Sr and Sm-Nd ages of ~330 Ma and suggested that the young ages recorded the crystallization of the sample. Concordant ages for numerous Martian meteorites have now been obtained using Rb-Sr, Sm-Nd, U-Pb, and Lu-Hf chronometers that support this contention. Although most researchers consider these ages to record igneous crystallization, some still support the older hypothesis that the young ages reflect secondary resetting of the isotopic systems by metamorphism (e.g., Bouvier et al., 2009).

Summaries of Sm-Nd ages for Martian meteorites can be found in Nyquist et al. (2001a) and Borg and Drake (2005). Like the Rb-Sr system, the Sm-Nd system can be used to define 4 general age groups for the shergottites of ~170 Ma, ~330 Ma, ~475 Ma, and ~575 Ma. In addition, the initial εNd values (Samarium-Neodymium, Model Ages, Springer Reference) determined from the Sm-Nd isochrons demonstrate a huge range from -7 to +48 (e.g., Borg et al., 1997; 2005). The initial εNd values, along with initial $^{87}Sr/^{86}Sr$ ratios, indicate that the shergottites are derived from source regions that have elemental abundances that range from incompatible-element depleted to incompatible-element enriched. Samarium-neodymium ages of ~1.3 Ga have been determined from the nakhlites (e.g., Shih et al., 1999) and ages ranging from 4.0 to 4.5 Ga have been obtained for ALH84001 (Nyquist et al., 1995a; Lapen et al., 2010). A sampling of Sm-Nd ages determined for the various types of Martian meteorites is presented in Table 3. In contrast to the Rb-Sr ages presented in the Rb-Sr chronology of meteorites (Springer Reference), this table emphasizes the more recent chronology for each meteorite because the newer data is generally less disturbed.

Table 3. Representative Ages and Initial Nd Isotopic Compositions of Martian Meteorites

Sample	Sm-Nd age	Initial εNd	Reference
Zagami (E)	166 ± 12 Ma	-7.23 ± 0.17	Borg et al. (2005)
EET79001B (I)	169 ± 23 Ma	-16.9 ± 1.4	Nyquist et al. (2001b)
ALH77005 (I)	173 ± 6 Ma	+11.1 ± 0.2	Borg et al. (2002)
QUE94201 (D)	327 ± 19 Ma	+47.6 ± 1.7	Borg et al. (1997)
Governador Valadares	1.37 ± 0.02 Ga	+16.7 ± 0.4	Shih et al. (1999)

Letters after shergottite names refer to incompatible-element characteristics of their source regions (E) = enriched, (D) = depleted, and (I) = intermediate.

Several lunar meteorites have been dated using the Sm-Nd system. Unlike many Apollo samples, the Sm-Nd isotopic systematics of most meteorites appear to be minimally affected by the capture of thermal and epithermal neutrons that are produced in the lunar subsurface by bombardment of galactic cosmic rays. The oldest sample is an anorthositic clast from Y86032 which yields and age of 4.43 ± 0.03 Ga (Nyquist et al. 2006) making it one of the oldest dated rocks from the Moon. Most other Sm-Nd chronometry has been applied to lunar basaltic meteorites. Samarium-neodymium ages of 2931 ± 92 Ma, 2993 ± 32, 3106 ± 44 Ma, and 2922 ± 85 Ma have been determined for NWA032, NWA773 NWA 4734, and LAP02205 (Borg et al., 2004; 2009; Elardo et al., 2014; Rakenburg et al., 2007) that are in good agreement with Rb-Sr ages determined on the sample samples. This suite of basalts is the youngest group of lunar rocks that have been dated from the Moon so far, and serves to demonstrate that there is significantly more geologic variation on the Moon than is represented in the Apollo (or Luna) sample collections.

Finally, the age of differentiation of both Moon and Mars has been estimated from Sm-Nd whole rock isochrons completed on lunar samples, including meteorites, and Martian meteorites. The age of lunar differentiation is determined using the Sm/Nd ratio estimated for basalt magma sources from measured $^{143}Nd/^{144}Nd$ ratios and $^{142}Nd/^{144}Nd$ ratios measured for the whole rocks. The model age is calculated from the slope of a line regressed through whole rock data on a ^{146}Sm-^{142}Nd isochron plot. The basis of these model ages is the assumption that isotopic variation observed in the basalt source regions reflects fractionation of Sm from Nd associated with solidification of the lunar magma ocean. Ages of 4329 $^{+40}/_{-56}$ Ma (Nyquist et al., 1995), 4352 $^{+21}/_{-23}$ Ma (Rankenburg et al., 2006), 4313 $^{+25}/_{-30}$ (Boyet and Carlson, 2007), 4340 $^{+20}/_{-24}$ (Brandon et al., 2009), and 4355 $^{+31}/_{-39}$ Ma (Gaffney and Borg, in review) have been determined by these studies. All ages are within uncertainty of the original model age obtained by Nyquist et al. (1995) and yield a weighted average age of 4341 ± 21 Ma.

The model age of Martian differentiation has been estimated using the slope of shergottite whole rock $^{142}Nd/^{144}Nd$ - $^{143}Nd/^{144}Nd$ isotopic data to be 4513 $^{+27}/_{-33}$ Ma (Borg et al., 2003), 4525 $^{+19}/_{-21}$ Ma (Foley et al., 2005), and 4502 ± 5 Ma (Symes et al. (2014). It has also been determined from ^{146}Sm-^{142}Nd whole rock isochron to be 4527 ± 18 Ma (Caro et al., 2008), and from model age determined on individual samples to be 4535 ± 7 Ma (Debaille et al. (2007). All ages are within uncertainty of the original model age determined on QUE94201 of 4525 ± ~25 Ma (Borg et al. 1997). The weighted average of all these ages is 4505 ± 11 Ma, indicating that the Moon differentiated significantly after Mars.

Conclusion

The Rb-Sr and Sm-Nd isotopic systems have been used to successfully constrain the timing of many events that occurred throughout Solar System history. These systems are complementary to one another, and are generally applied to the same samples during individual investigations. As a result, concordant ages from both systems provide strong evidence that they record the crystallization age of a sample. Nevertheless, these systems can be disturbed by strong metamorphism occurring on a parent body or planet, and by weathering occurring on Earth. Weathering is particularly problematic for the Rb-Sr system because it is very easily disturbed by this process. Absolute ages are based on measured ^{87}Rb, ^{147}Sm, and ^{146}Sm decay constants. Whereas the absolute values of the ^{87}Rb and ^{147}Sm decay constants appear to be fairly well constrained, the value of the ^{146}Sm decay constant is less certain and needs further refinement. Application of Rb-Sr and Sm-Nd systems to meteorite samples has been most successful for martian and lunar meteorites, although reasonable Sm-Nd ages have also been obtained from many primitive achondrites. Disturbance of the Rb-Sr system in many primitive achondrites has led to the development of BABI model ages which provide a relative Rb-Sr chronology for these samples. Samarium-neodymium model ages for planetary differentiation have also been obtained for Moon and Mars, that imply the Mars formed prior to the Moon.

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